

Conference Summary

Hagai Netzer¹ and Joseph C. Shields²

¹*School of Physics and Astronomy and the Wise Observatory, Tel Aviv University, Tel Aviv 69978, Israel*

²*Physics & Astronomy Department, Ohio University, Athens, OH 45701 USA*

Abstract. The meeting in Xi'an covered the enormous and continuously expanding area of AGN research, from theory to the most sophisticated observations and from γ -ray energies to long radio wavelengths. The short summary below gives some, but definitely not all, highlights and new results presented by the participants.

1. Black holes

The main progress in this area in recent years, that enables comprehensive statistical studies of active black holes (BHs), is the success of the large reverberation mapping project. This allows reliable estimates of broad line region (BLR) sizes and BH masses. The method was reviewed by S. Kaspi and B. Peterson with additional (somewhat intriguing and perhaps conflicting) suggestions by M. Benzt. The talks summarized the 10 years long project and illustrated the accuracy of the “single epoch mass determination” method. The original reverberation mapping work was based on the measurements of the optical (5100Å) continuum and the H β line. It provided good (factors 2–3 uncertainty) estimates of BH masses at low redshifts, where H β is accessible to ground-based spectroscopy. The main concern and the biggest unknown is the extension of the method to high redshifts where H β measurements are no longer available. While some workers suggest that the combination of the UV continuum and the C IV λ 1549 line is a proper substitute for the H β –L(5100Å) method, others quote factors of 3, 5 and even larger uncertainty on the masses obtained in this way. A possible way to proceed is to use ground-based J, H and K spectroscopy to measure the H β line in high redshift sources. In principal, this could help solve most problems. In reality, the observations are difficult and the number of AGNs measured so far quite small.

Notwithstanding those difficulties, we have seen several attempts in this meeting to explore the land of BH mass at both extremes. Very low mass BHs, like those presented by J. Greene, are very useful indicators of the relationship between the host galaxy and the central BH at low redshifts. Very high mass BHs, those approaching $10^{10} M_{\odot}$ and presented by F. Hamann, are some of the best indicators of the early evolution of massive galaxies. Additional pieces of information, related perhaps to the metal enrichment in high redshift sources, are the correlation of BLR metallicity with either BH accretion rate or BH mass.

Of the various other talks related to BHs we mention the very interesting suggestions by A. Marconi and Ran Wang to construct the fundamental plane for active BHs. Such methods have been very successful in studying various types of normal galaxies and can, perhaps, work also for active galaxies. At this stage it is not very clear what the best parameters are. One suggestion involves the X-ray and radio luminosities and the BH mass. This would make it difficult to include radio-quiet AGNs in the same scheme. The idea needs more exploration and refinement.

2. Accretion Disks and X-ray variability

AGN accretion disks have been explored, in great detail, since the late 1980s. These are complicated systems that defy most attempts to compute their emergent spectrum even for static, non-disturbed disks. Needless to say, unstable disks, and those with strong magnetic fields and hot coronae, are even more complicated. Thus, it is no surprise that progress in this area has been slow.

Some refreshing news on more realistic disk calculations was reviewed by O. Blaes who introduced a very detailed attempt to model disks on all scales. The new calculations contain several of the earlier missing ingredients. MHD effects are included and suggest that AGN disks are probably supported by magnetic pressure, which is more important than the gas and the radiation pressure. The comparison of broad-band calculated spectra with observations of SDSS sources suggests good agreement in the optical part of the spectrum but less agreement with the UV part. Even specific spectroscopic features, like the Balmer jump, can be computed, reliably, by the new codes.

Unfortunately, there is still a long way to go and there are various components that are not included in the calculations. A notable example is the absence of a hot corona which made several of the X-ray participants unhappy. We will have to wait a little longer before such components are included and before we can answer the very interesting question of whether the soft (< 1 keV) X-ray spectrum of AGNs, at least in those objects hosting the smaller BHs, is the short wavelength tail of the central accretion disk spectrum.

X-ray variability is definitely an area of great excitement (physically as well as the reaction of the audience). We have heard several talks that summarized not only major discoveries of recent years but also the comprehensive analysis of the huge data base on AGN variability. Some of the highlights include

Narrow variable X-ray lines: These were reviewed by J. Turner who showed that such features are a common phenomenon. So far they have been observed in eight AGNs and seem to originate very close to the BH, in the same area of the disk thought to produce the (by now somewhat questionable) relativistic disk lines. The narrow lines change their velocity and intensity and seem to have extremely large equivalent widths, up to 100 eV in some cases. Such strong components cannot be explained by any disk-corona models. They may be used, when better statistics are available, to infer and perhaps even measure the BH spin.

Broad relativistic X-ray lines: This is still an area of some debate. While some workers believe that the phenomenon has been observed in almost all

AGNs, others maintain that most of those (perhaps all but two or three) are not real and the data are entirely consistent with narrow $K\alpha$ lines. The statistical evidence was summarized by T. Yaqoob who defended the view that such lines are very common and seen in 25–50% of all sources. This view is definitely not shared by the entire X-ray AGN community. Perhaps the only safe conclusion is that the parameters needed to describe broad $K\alpha$ lines, in combination with the unknown shape of the 4–8 keV continuum, leaves too much freedom for the suggested models.

X-ray variability and BH and accretion disk physics: P. Uttley reviewed the great progress in this area. Several long term monitoring campaigns are starting to pay off and very sophisticated time series (or power spectral densities - PDSs) analysis can be carried out. It seems that a break in the power-spectrum is a common feature but the analogy between BHs in X-ray binary systems and in AGNs is more complicated than claimed in earlier works. According to Uttley, the variability pattern can be used to distinguish among several physical models, such as accretion flows, jets, etc, as the origin of the observed variability. The first of those seems to be the best current explanation. There are several exciting new results some based on single sources and others on the sample properties. In one case, (NGC 4051) there is clear indication for QPO type variability. For the entire sample included in the review, that contains small (X-ray binary) and large (AGN) BHs, the break frequency in the PDS (still the most fundamental property) obeys $t_{\text{break}} \propto M_{\text{BH}} \dot{M}^{-1}$ where \dot{M} is the normalized accretion rate.

3. Jets

Perhaps the most rapid progress in AGN observations in recent years is related to blazars and the very high energy observations of such sources. Most important perhaps is the big advance in atmospheric Cherenkov Telescope technology. We have seen beautiful observations of jets from the radio to X-ray, GeV and even TeV energies and details that were not available even a couple of years ago. Some of the new results were presented by S. Wagner who argued that the source of the observed γ -rays is inside the jet. He also argued that at least in one source (Mkn 421) there is some TeV emission. There is also new evidence for low energy cut-offs and extremely compact emission regions, of order of the Schwarzschild radius of the central BH, in some sources. L. Maraschi showed us newly detected extremely large X-ray jets (courtesy of the *Chandra* observatory) confirming high electron temperatures many kpc away from the center.

Unfortunately, in this area the models seem to be lagging behind, not because they are not sophisticated enough, some are extremely complex, but because of the huge number of free parameters. Very interesting ideas have been presented by M. Boettcher who argued for the differentiation of hadron jets and lepton jets. We have learned that spectral information, by itself, is not enough to differentiate between all those possibilities and measurements of variability, preferably on very short (intra-day) time scales, are sorely needed. It seems that none of the available models can uniquely explain the new observations. In

this respect, the very high energy land of AGN is yet another area of astronomy where observations lead the way.

Powerful jets, be it in the radio or the Gamma-ray, may well be related to the structure and the stability of the central accretion disk. This was explained in great detail by J.M. Wang who emphasized the very important and likely physical correlation between the very small (innermost parts of the accretion disk) and the very large (Mpc size jets) scales.

4. Winds and outflows

This area is progressing very rapidly, observationally and theoretically. Much of the progress is due to several superb spectroscopic observations, in the ultraviolet, optical and X-ray bands. Present day X-ray wind models can be compared to many dozens of X-ray absorption lines, in a handful of sources, that indicate the motion of the “warm” ($\sim 10^5$ K) gas. The number of UV lines is not as large but their velocity can be investigated to a superb accuracy, a few km/sec. An extremely nice result of this type was given by M. Crenshaw who showed the first example of a cool component, in NGC 4151, that is seen both in emission and in absorption. There were other interesting results related to X-ray observations. One example is the M. Guainazzi sample of many Seyfert 2s that, despite having only moderate S/N (XMM-Newton) observations, seem to be similar in most properties to NGC 1068.

There are big discrepancies between various models (or explanations). The Guainazzi sample of Seyfert 1s and 2s suggests that the X-ray absorbing gas seen in the first class of sources (the so-called “warm absorber”) is the X-ray emitting gas seen in the second class. This would indicate that the size of the warm-absorber region is tens and perhaps hundreds of pc. On the other hand, the F. Nicastro analysis of the X-ray spectrum of NGC 4051, suggests a sub-pc size of the warm absorber in this source. Is this unique to NGC 4051 or, perhaps, there is a problem of interpretation? Interestingly, the distance of the warm absorber in NGC 3783 (perhaps the best studied case so far) as deduced from a detailed photoionization analysis, is roughly the geometrical mean of the two (about 1–3 pc).

A beautiful demonstration of the usefulness of the multi-wavelength approach was given by S. Gallagher who reviewed BAL QSOs. Geometry must be very important in such cases. It determines the fractional amount of UV and X-ray radiation that reach the observer and perhaps also the total width of the absorption troughs. The combination of X-ray and UV observations provides a powerful tool to infer the viewing angle to the center and the column density of the absorbing gas. A key observational result is that the X-ray luminosity gets weaker when the line velocities are higher. It seems that the ratio of $L(\text{UV})/L(\text{X-ray})$ in those sources can be explained by a high-mass wind that drives material almost in parallel to the central disk surface. So far we have been limited by the very small number of sources needed for this analysis. However, the numbers are getting larger (35 in some of Gallagher’s diagrams) and a clearer picture starts to emerge.

The theory developed to explain these observations is, again, lagging behind. Much of what was shown in the meeting regarding wind models was based

on numerical modeling of photoionized gas which is streaming along radial or curving, even spiraling stream lines. Despite a great body of observations, those models are not unique. As explained by D. Proga, this is not surprising given the huge parameter space in disk-wind models. It is not even clear whether we are witnessing a smooth freely expanding wind or whether there is a ballistic type motion that requires confinement.

Theoretical arguments of a different type were presented by D. Chelouche who argued that thermal winds can explain many of the observed properties. Such winds are likely to develop on large scales, between the BLR and the NLR, and the typical velocity is consistent with a temperature of several million degrees. Such hot outflows can carry with them cooler gas that is responsible for much of the absorption. The speaker reminded us also of the importance of high quality observations and the combination of UV and X-ray data. Apparently, this combination in stars resulted in the suggestion that previous mass outflow rate estimates were off (too high) by a factor 10 (!!!). Can this also be the case in AGN outflows?

5. The broad line region

There are several important issues regarding the BLR geometry and gas composition although none is very new. W. Kollatschny presented the best case, so far, for measuring gravitational redshift components in broad emission line profiles (the $\text{HeII } \lambda 4686$ line in Mkn 110). This is a tricky issue that requires a unique combination of variability and velocity because the magnitude of the shift is relatively small. There is clearly a need to look for lines that originate closer to the black hole, where the effect is stronger. Two dimensional transfer functions were also presented in the same review. They beautifully demonstrated the ionization and velocity stratification and prove, yet again, how useful and how time consuming the application of this method is.

The SDSS sample provides a great opportunity to investigate several BLR properties as a function of luminosity. Some new results were presented by Nagao referring mainly to the gas metallicity and using grouped rather than individual sources. Apparently, metallicity is luminosity (but not redshift) dependent. Here, again, it seems difficult to decide whether the luminosity or the accretion rate are driving the observed correlations.

Dust is an important ingredient in all regions, from the outskirts of the BLR to well inside the host galaxy. The implication to the BLR size were reviewed by A. Laor as discussed in the next section.

Finally, it was nice to be reminded that some of the main puzzles of BLR research are still with us, after 20 or more years of study. One such example was discussed by M. Joly who pointed out that collisional (rather than photoionized) gas may be a necessary ingredient to explain the strong observed FeII lines. Another outstanding question is the so-called ‘‘Baldwin effect’’ that was reviewed by J. Shields. There are several suggested explanations for this line-to-continuum correlation. Is the correct explanation somewhere in that list? We probably need more time, and perhaps more data to answer this question.

6. Dust

The role of dust in AGNs was a major theme at this meeting. It is clear more than ever that a detailed understanding of the effects of dust is essential to progress in the field. The influence of dust emerged in several lines of discussion.

Dust is central to our understanding of the *torus*. Recent observations described at the meeting indicate that this structure is smaller than originally thought, but resolved in at least some nearby systems. NGC 1068 remains a favorite object of study; for this source, W. Jaffe showed $8 - 13.5\mu\text{m}$ interferometric measurements that reveal a source with an extent of $\sim 2 \times 3$ pc that can be identified with the torus. For the same object, R. Davies presented infrared H_2 detections that likely trace the same structure on somewhat larger scales.

In addition to being small, the torus is likely to be clumpy. As reviewed by M. Elitzur, a clumpy structure makes it possible to reconcile the infrared spectral energy distribution and the implied (large) range of grain temperatures with the torus's small radial extent. The application of these ideas to the specific case of NGC 1068 was presented by S. Hönig, based on 3D radiative transfer simulations. In this picture, a single clump can be highly optically thick, allowing a large gradient in grain temperature to exist between the irradiated and shadowed sides of the cloud.

Dust remains essential to understanding the Seyfert 1/2 dichotomy. The dust sublimation radius evidently defines the outer boundary of the broad-line region (BLR); A. Laor reviewed the theoretical basis for this statement, and M. Suganuma presented the current status of reverberation mapping for the infrared continuum versus UV/optical line emission in Seyfert nuclei. The results consistently place the infrared-emitting medium just beyond the BLR, for sources spanning a range of luminosity and hence radial scaling. The infrared emitter presumably corresponds to the torus, which causes us to observe a Seyfert 2 nucleus when our line of sight to the BLR is obscured by the dusty medium. However, as noted by Elitzur, the fact that the obscuring structure is lumpy rather than a homogeneous donut means that obscuration and classification of an AGN as Type 1 or 2 becomes a probabilistic function of inclination rather than a strict function of viewing angle.

While this picture of geometric unification is clearly applicable to many sources, the possibility remains that some Type 2 AGNs simply lack a BLR. Laor noted that in low-luminosity systems the dust sublimation radius may move in to sufficiently small radii that the (dust-free) BLR disappears. Alternatively, Elitzur sketched a scenario in which the BLR can be associated with a wind emerging from the accretion disk, and posited that this outflow disappears at low luminosity.

An important tool for discovering hidden broad-line regions (HBLRs) in apparent Seyfert 2s has been spectropolarimetry. E. Moran reviewed the status of spectropolarimetric surveys and noted that much of the work to date is characterized by strong selection effects and sensitivity biases. As a result it is difficult to draw meaningful conclusions when comparing properties of objects with and without detected HBLRs, which may be relevant to the question of whether Seyfert 2s lacking a BLR exist. Surveys are currently underway to improve on this situation, but in interpreting the spectropolarimetric results it is important to recognize that absence of evidence does not constitute evidence of

absence, since the discovery of a hidden BLR by this method remains dependent on the presence of a suitable scattering medium.

Where dust survives near the AGN, it may play a fundamental role in influencing the state of gas irradiated by the central source. B. Groves reviewed models for the narrow-line region (NLR), and noted that radiation-pressure-dominated dusty clouds likely provide the best physical framework for understanding the tuning of parameters implied by the observed emission-line ratios. In specific instances, however, the structure and energetics of the NLR may be dominated by other phenomena. N. Bennert showed examples in which circum-nuclear star formation turns out to be a significant contributor to apparent NLR emission; J. Holt and K. Inslip provided case studies in which AGN feedback that includes radio jets gives rise to large-scale outflows in the NLR.

A final important aspect of dust associated with AGNs concerns high-redshift quasars and the evolutionary state of their host galaxies. The degree to which star formation precedes the onset of quasar activity at early epochs is of great interest for understanding the co-evolution of black holes and their surrounding stellar systems. F. Hamann reviewed abundance constraints relevant to this topic; an increasing number of observations point to large far-infrared luminosities in many high- z quasars, which in turn necessitate a minimum mass of dust formed from heavy elements produced by stellar nucleosynthesis that preceded the quasar activity we now observe. The implied amounts of star formation can be large and indicate that galaxy-sized stellar systems were already in place before the quasar turned on, in many cases.

7. Probing Dust

A growing number of strategies for probing the properties and influence of dust in AGNs were discussed at the conference. These include

IR Spectroscopic Features: A. Lee, E. Sturm, L. Hao, R. Deo, and others provided illustrations of the power of infrared spectroscopy for probing the physical properties of dust, its geometrical distribution, and its role as a reprocessor in AGNs. Of particular interest are the ~ 10 and $\sim 18\mu\text{m}$ silicate “humps” and several PAH emission features. The impact of the *Spitzer Space Telescope* on this field has been significant, and was one of the highlights of this meeting.

XAFS: Methods usually associated with condensed matter experiments in terrestrial labs may see increasing application to astronomical dust in the future. As described by J. C. Lee, a promising example is X-ray absorption fine structure (XAFS) analysis. Observation of XAFS features with next generation X-ray observatories could provide a tool for measuring the composition of grains when a strong background X-ray source is available, as in an AGN.

Extinction Law: The wavelength dependence of extinction contains information on the physical properties of the scattering and absorbing grains, and considerable effort has been invested to use the extinction law to learn

about dust in the local interstellar medium. The situation is more complex in AGNs, where the unattenuated SED in a given source is not well known and hence measurement of the extinction law itself is less secure. Studies to date provide suggestive evidence that the grain size distribution in AGNs may be quite different from that in the local ISM, although these results have proven controversial. At this conference B. Czerny reviewed the state of our understanding of the extinction law in AGNs based on analysis of AGN ensemble SEDs. She presented a cautionary exercise in which the multi-epoch spectra of a single variable source, Mrk 335, were analyzed using the method appropriate for ensemble analysis, which assumes that SED variations stem from differences in the amplitude of extinction; the Mrk 335 analysis produced an extinction law quite similar to the ensemble result, even though the SED variations among its spectra probably have little to do with variable extinction! There is clear evidence that the grains in AGNs differ from the local ISM (e.g. AGNs lack a 2175 Å extinction feature), but more effort will be needed to definitively measure the extinction law and draw detailed conclusions.

Unification Tests: For cases where geometric unification seems to be a good bet (i.e. differences stem from viewing angle), a comparison of the properties of Type 1 and Type 2 objects provides constraints on the optical depth and spatial distribution of dust. At this meeting, K. Cleary presented the results of a study comparing 3C quasars and radio galaxies where *Spitzer* observations make it possible to separate thermal and synchrotron contributions. The two populations show consistent luminosities, validating the unification assumption, after correction is made for nonthermal emission in the quasars and absorption in the radio galaxies; for the latter sources, the results directly yield the infrared optical depth for the obscuring medium. B. Schulz presented related results for infrared fine-structure lines and silicate features in the 3CR sources, which validate the unification picture while placing constraints on the torus dust properties.

8. Beyond Dust

8.1. The X-ray Absorbing Medium

Several aspects of AGNs discussed at the meeting that might seem plausibly linked to dust in fact probably require other explanations. A dusty medium identified with the torus is responsible for optical obscuration, but as reviewed by R. Maiolino, an additional component of dust-free gas is required to explain the X-ray absorption observed in at least some sources. The clearest examples are those that display X-ray absorption indicative of large column densities, but nonetheless feature broad UV/optical lines. Likewise, the total N_H inferred from X-ray absorption is often greater than that implied by the dust optical depth at 10 μm . Variability in the absorbing column on short timescales suggests that the high- N_H X-ray absorber characteristically resides at radii comparable to that of the broad-line region; a particularly striking case study was described by G. Risaliti, who showed a sequence of X-ray measurements for NGC 1365 interpreted as a change from Compton-thin to Compton-thick absorption, and a

return to Compton-thin conditions, over a total span of four days. As noted by Maiolino, the implied size scale in such cases is smaller than the dusty medium resolved in mid-IR continuum emission. In Elitzur’s theoretical picture the dominant X-ray absorber, along with the BLR, is identified with the dust-free inner part of a wind emanating from the accretion disk.

There is a need as well as opportunities for improving our understanding of the X-ray absorbing medium. Additional investigation of the time variability of absorption in individual sources would clearly be valuable for identifying the location and structure of the absorber. In the study of AGN ensembles, Maiolino argued that our knowledge of X-ray absorber phenomenology remains severely limited by selection biases that cause highly absorbed sources to be under-represented in typical samples. The X-ray Background continues to be an important constraint on the total number of absorbed sources as a function of redshift. Maiolino cautioned that some objects with reflection-dominated spectra may not be Compton-thick but rather cases where the central X-ray source has shut down recently and the reflecting regions remain visible due to light travel-time delays. In principle such examples of “fossil reflection” provide another means of probing the extent and coverage of high column-density gas in the nuclear environment.

8.2. Seyferts versus LINERs

As mentioned above, radiation pressure acting on dust in the NLR may be important in tuning the ionization and other properties of the emitting plasma, but it seems that some additional parameter is involved in determining the emission spectrum of a given source, if we consider LINERs as well as Seyferts. In the past it was possible to consider LINERs and Seyferts as forming a continuous distribution spanning the AGN side of the usual line-ratio classification diagrams. This picture has changed as a result of measurements of very large spectroscopic samples of galaxies from the Sloan Digital Sky Survey. As discussed by Groves, the distribution of AGNs in the line-ratio diagrams is genuinely *bimodal*, implying that the LINER/Seyfert distinction has some real physical meaning and is not simply an arbitrary division.

The separation in properties may arise from differences in the ionizing SEDs for the two classes of object, such that LINERs lack the optical/UV “big blue bump” characteristic of Seyfert nuclei and quasars. Analyses using SDSS data by A. Constantin and by J. Greene indicate that at low redshift, LINERs and Seyferts of similar luminosity have characteristically different black hole masses, with LINERs typically having larger M_{BH} . A consistency can then be drawn if the correspondingly lower L/L_{Edd} for the LINERs results in a different accretion structure (e.g. an advection-dominated accretion flow or other radiatively inefficient accretion flow) producing a harder continuum than in the Seyferts. At this conference I. Marquez presented new X-ray observations of LINERs, confirming earlier indications that nuclear point sources are often, but not always, evident. There is some confusion in the literature stemming from the fact that extended nebular sources associated with infrared-luminous starbursts sometimes show emission-line ratios formally consistent with a LINER classification, and are referred to as such, although their energy source and physical nature are probably very different than in truly nuclear sources. D. Rupke presented new *Spitzer*

measurements of fine-structure emission lines for both categories of sources; the infrared lines allow a clearer differentiation of the two types of LINER emitters, compared with the optical line ratios.

9. Other New Results

A variety of other new and noteworthy results were presented at the meeting. A list of some of the findings that caught our attention is given here; this summary is in no way comprehensive.

New composite QSO spectra: Z. H. Shang and E. Sturm presented new composite spectra which give a nearly continuous coverage from $\sim 0.1 - 40 \mu\text{m}$, which takes advantage of recent *Spitzer* measurements. The result beautifully illustrates the detailed continuum structure through this band-pass, which the current paradigm interprets as a combination of emission from the accretion disk and circumnuclear dust.

A clustering constraint on AGN companions: The extent to which AGN activity is related to interaction with companion galaxies has been the subject of controversy for some time. At this conference C. Li presented the 2-point cross-correlation function for an SDSS sample that includes a large number of narrow-line AGNs. This analysis finds a small excess of companions at separations of $< 70 \text{ kpc}$, such that $\sim 1\%$ of AGNs have an additional neighbor beyond that expected for normal galaxies. The excess increases at larger accretion rate, as measured by $L([\text{O III}])/M_{\text{BH}}$ (where M_{BH} is estimated from the $M_{\text{BH}} - \sigma$ relation); however, if substantial numbers of AGNs are linked to close interactions, the resulting mergers are already complete in most cases, such that a companion is no longer evident.

High-velocity HI wings as a tracer of feedback: The influence of AGNs on their surrounding galaxy and beyond is a critical issue in understanding galaxy evolution. R. Morganti presented observations of 21-cm H I absorption in radio galaxies which reveal outflows with speeds of up to $\sim 1000 \text{ km s}^{-1}$, presumably originating in interactions between radio jets and the surrounding medium. The fact that the detected gas remains *neutral* while being accelerated to such velocities is remarkable. The total mass and kinetic energy participating in such an outflow may be significant, and in turn can be expected to have nontrivial consequences for the host galaxy and surrounding intergalactic medium.

Star formation indicators in the presence of an AGN: N. Levenson reviewed the available tools for distinguishing the contributions from an AGN and from young stars in a given object. She noted that caution is often warranted; an example is the far-infrared continuum, where the emergent SED is established to a significant degree by the geometry of the dust distribution, rather than simply the energy source. An AGN can also modify the observable properties of star-forming regions such that they appear different than in systems lacking an accretion source. An informative

example was presented by R. Mason for NGC 1097. This galaxy displays a young nuclear star cluster as well as a weak AGN; both are energetically significant, but the PAH emission that would be expected to be excited by the cluster is absent, presumably due to PAH destruction by the AGN's radiation field.

The Stellar Initial Mass Function in AGNs: S. Nayakshin reviewed the observational evidence for a top-heavy IMF in the Galactic Center and presented arguments as to why this might be expected for star formation that occurs in disks on small scales in active nuclei. An intriguing consistency was reported by M. Sarzi, from an analysis of *Hubble Space Telescope* spectra for the central ~ 10 pc of a sample of Seyfert 2 galaxies. Those objects show evidence for young stars in some instances, but the majority of starlight seen traces old (many Gyr) stars, and intermediate-age populations are conspicuously absent. If the IMF is indeed skewed to high masses, this could explain a lack of observable signatures of star formation for ages beyond $\sim 10^8$ yr, consistent with what is seen.

New metallicity diagnostics for the NLR: Accurate measurement of metallicity in the NLR is a long-standing problem, and it remains challenging to separate out the influence of abundance from other thermal and ionization effects in determining emission-line strengths. T. Nagao described strategies for constraining NLR metallicity from rest frame UV emission features, which is of particular interest for high-redshift sources in which such features are observed at optical wavelengths. One option that shows considerable promise is to use a combination of the C IV/He II and C III]/C IV line ratios; the former is sensitive in part to abundance while the latter is sensitive to ionization parameter, allowing separation of the two.

Deviations from $M_{BH} - \sigma$ at moderate redshift: The correlation between black hole mass and stellar velocity dispersion for the host galaxy has generated enormous interest as a clue to processes that link the growth and evolution of an AGN and the surrounding stellar body. A full understanding of this relation requires that we measure the correlation as a function of time and not simply at the present epoch, in order to understand just how closely nucleus and host are locked in their evolution. M. Malkan reported results of a study for Seyfert 1 galaxies at $z = 0.36$, with M_{BH} estimates derived from emission-line measurements. The results indicate that black hole masses at a given stellar velocity dispersion are larger on average by a factor of ~ 4 in these objects, compared with what is found locally. Preliminary analysis of *HST* imaging provides supporting evidence for this conclusion, in that the bulge luminosities are low compared to what would be expected from the M_{BH} estimates.

New candidates for tidal disruption of stars: Stars wandering too close to a black hole are headed for trouble. While theoretical predictions for the result have been available for some time, credible candidates for this phenomenon have only appeared rather recently. S. Gezari presented remarkable results for a flaring event in the nucleus of an inactive galaxy that

was observed at multiple epochs with multi-wavelength coverage. The results are consistent with a tidal disruption event, and from the measured SED and time evolution it is possible to constrain the black hole mass; a constraint on the black hole's spin may also be possible, since the spin determines the location of the innermost stable orbit and hence the inner extent of a transient accretion disk. Future studies of this type will be facilitated with the new capability for large-scale temporal sampling of normal galaxies provided by Pan-STARRS and LSST.